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Effect of Background/Foreground Color Coding on Detection in Acoustic Data Displays

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Considerable work is going on to determine how color should be used to improve the legibility of sonar CRT displays. One of the questions concerns the color that should be used for the background on such displays. Some operators have expressed the opinion that a blue background is preferable to the standard black background because blue is less fatiguing and may enhance target detection. In this study, the ability of experienced sonarmen to detect red, yellow, and green target tracks of equal contrast on blue and black backgrounds was measured on a simulated sonar display. There were no differences in the detectability of the different targets on the two backgrounds, and there was no agreement among the operators as to the best color cominations.

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INTRODUCTION

The monochromatic CRTs in sonar control rooms may soon be replaced in the new sonar systems with color CRTs. To implement color coding for these displays, a number of factors must be taken into consideration. Research bearing on several of these factors has been carried out. To begin with, the advantages and disadvantages of color coding as an aid to improving perceptual performance discussed in the psychological literature have been summarized and suggestions made for the choice and use of colors in the new SUBACS sonar system.[1] The combinations of colors that produce the greatest perceived difference on the sonar CRTs have been investigated under the various colors of ambient light found on submarines.[2]

Another question that has been raised is what is the most desirable background color? A number of operators have expressed the opinion that a blue background is a more comfortable and less fatiguing color than the standard black background. This proposal is of interest, since blue is generally avoided for alphanumerics and could well be restricted to use as a background color. This study sought to determine whether or not detection of chromatic targets, equated for contrast on a blue background and on the typical black background, was superior with the blue.

DISCUSSION

SUBJECTS AND EQUIPMENT

Six subjects were chosen to participate in the experiment. All were experienced sonar operators with visual acuity corrected to 20/20 and normal color vision. The subjects were familiar with the type of sonar display used in the experiment and had experience at sea on monochromatic CRT sonar systems.

The sonar display was simulated using a VAX 11/780 computer, a RAMTEK 9400 display generator, and a 48-cm (19-in.) Matsushita Standard Phosphor color monitor. The addressability of the monitor was 1024 lines by 1280 pixels (100 pixels to the inch). The C.I.E. chromaticity coordinates (x,y) of the phosphors were 0.60, 0.34 for the red, 0.28, 0.59 for the green, and 0.16, 0.07 for the blue. The subjects sat approximately 40 cm (16 in.) from the screen, which subtended a visual angle of 36 deg horizontally and vertically. The data fields to which the subjects were attending subtended 30 deg horizontally by 7 deg vertically. Illumination was provided by two fluorescent tubes located above and slightly behind the subject and mounted in a fixture identical to those found on submarines. The lamps were covered with neutral-density filters that reduced the illumination falling on the screen to 0.5 foot-candle as measured by a Tektronix model J16 photometer with a J6511 illuminance probe.

The sonar display simulated a spherical array passive broadband (SAPBB) 4 D/E STA/ITA-ITA display (figure 1) with bearing along the x-axis, time along the y-axis, and the amplitude of the signal (coded by the intensity of the pixel) along the z-axis. The subject's task was to detect a target in one of the top four grams under one of the six different combinations of foreground and background color.

The display format was representative of that presented in an actual sonar system. In our simulation, four grams of short-time averaged (STA) data were displayed above four grams of intermediate-time averaged (ITA) data, but the ITA data were static and all detections were made in the STA fields. The bottom four grams were filled with static Gaussian noise. Eight luminance levels for pixel encoding were used, the same number employed on typical sonar displays.

Subjects were tested under six different conditions -- two background and three foreground colors containing the acoustic data, subsequently referred to as foreground colors. The display background was either black or blue. The background consisted of the entire display surface that did not contain any alphanumeric or raster data. The three foreground colors were either red, yellow, or green. The red and green colors and the blue background were produced by turning on only one gun. The yellow color was an equal mixture of the red and green guns. The data marking density was 50%; that is, at any given instant, half of the pixels in the data field were in the background color.

COMPARISON METHODS

The eight luminance levels of the data colors were determined prior to data collection by a psychophysical matching procedure. The black background was first produced by adjusting the brightness control of the CRT such that the display portion of the screen was the same brightness as the non-display edges of the screen, under the test level of illumination. The luminances of the red, yellow, and green colors were adjusted independently using a Photo Research photometer (model PR-1510 D-UB) such that the lowest luminance level represented an increase by a factor of square root of two over the luminance of the black background. The other seven luminance levels were also adjusted so as to be separated by the same factor. The square root of two relationship was chosen because it is the value used to quantize luminance levels in actual sonar displays.

Once the various luminance levels were established for the three colors on the black background, four observers adjusted the luminances of the three colors on the blue background, one at a time, such that the brightness difference between these colors and the blue background was equal to the difference between the same colors and the black background for all eight levels. The procedure was as follows. The black background was displayed on the left of the screen and the blue background on the right, with a square containing one of the foreground colors in the center of each background.

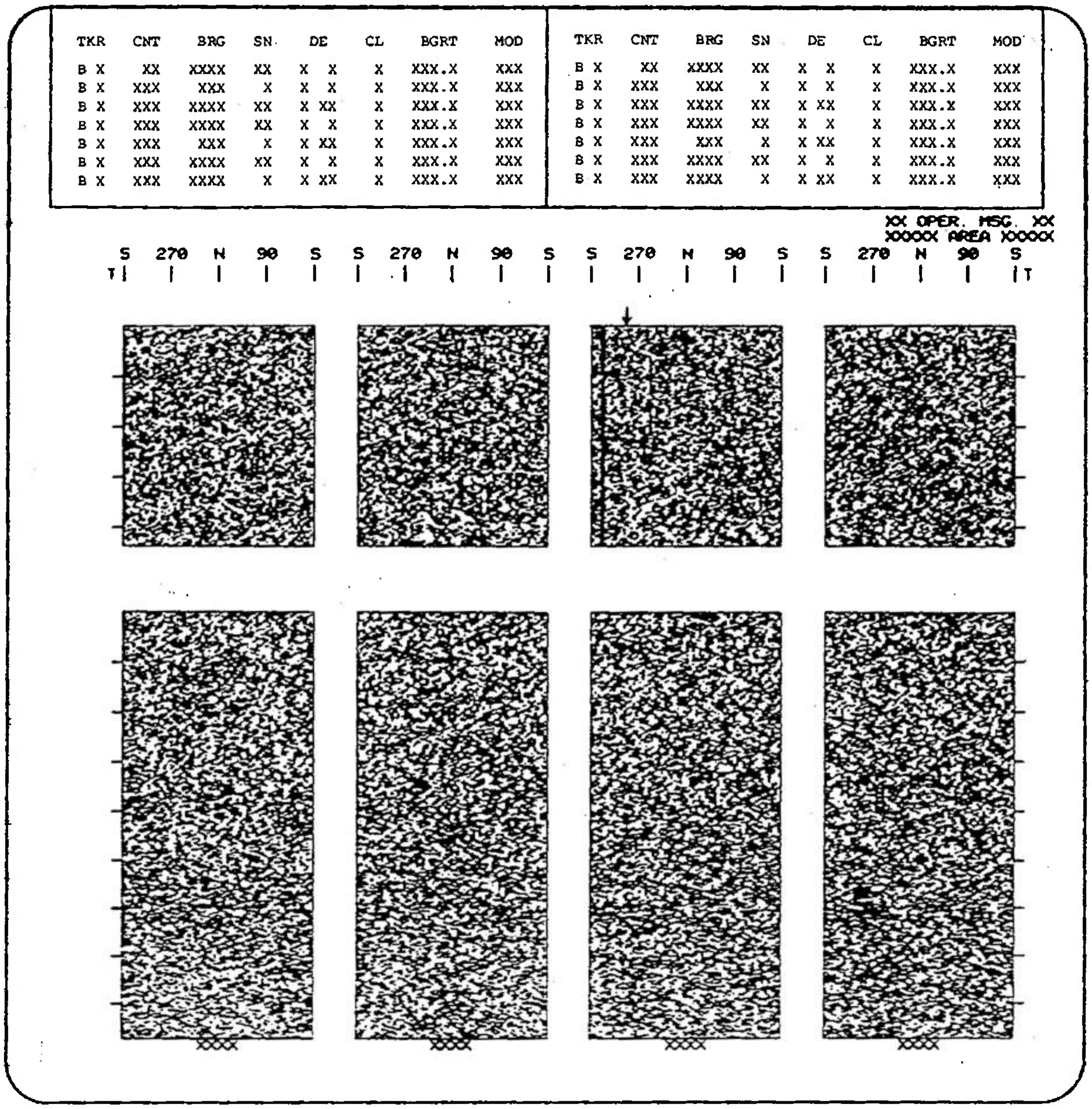


Figure 1. Simulated SAPBB 4 D/E STA/ITA-ITA Display

The luminance of the right square (on the blue background) could be independently adjusted. A neutral density filter was placed in front of the foreground color on the black background such that the foreground square was just visible. The same neutral density filter was then placed in front of the foreground color on the blue background and the luminance of the foreground color was adjusted until it was just visible. This was done for each of the eight levels of the three foreground colors by four observers. The averages of these four judgments were then used as the luminances for the eight levels of each of the colors on the blue background. Previous research has suggested that luminance contrast plays a large role in detection of colored targets on colored backgrounds.[2] Visually equating the step sizes of the foreground colors to both backgrounds equated the luminance contrast of data color to background color.

Each of the top four grams contained 60 beam positions (bearing increments) along the x-axis. Targets appeared on one of the top four grams in a randomly determined beam position, with the exception that they were not allowed to appear within two beams of the edges of a gram (figure 2). A target was modeled as being fixed in bearing. It, thus, consisted of a single straight vertical line, three pixels in width, which appeared in only one of the four D/E grams, on a background of Gaussian noise. Only one target was presented at a time. It began at the top of the gram and waterfalled downward with the noise. The signal level of the target was calculated according to

$$\text{Signal level} = \text{Noise} + 10.0^{(\text{Target SNR}/10.0)}.$$

The starting target SNR was a randomly determined integer between -10 and -12 dB. Pilot testing showed these levels to be below threshold. Target SNR was then increased in discrete steps of 1 dB every 10 seconds. The variable starting target SNR precluded the subject from using time as a clue to when the target was most likely to become visible.

Subjects were instructed that their task was to detect a target, as quickly as possible, in one of the top four grams, and, using a trackball, move the cursor arrow at the top edge of the gram so that it pointed to the location of the target. When the cursor was in place, the subject pressed a button registering his response with the computer. To allow for slight inaccuracies in the operator's positioning of the trackball, cursor placements within ± 1 beam of the target location were considered correct responses. With the button pressed, the computer recorded whether the response was a detection or a false alarm. If it was a detection, the computer recorded the total time elapsed to detection, the SNR at which the target was initially presented, the target SNR at the time of detection, and the target beam number. Correct responses resulted in the generation of a new target at a newly randomized location. If it was a false alarm, this was noted but no other data were recorded, and the target SNR continued to increase in 1 dB steps every 10 seconds until it was detected. In either case, the subject received no feedback. Fifty detections were necessary for a session to be completed. The order of background and foreground color combinations was determined separately for each of the subjects by randomization without replacement. Two conditions per subject were run each day in the early evening or early morning with a short break between conditions, resulting in three sessions of approximately one hour each per day for each subject. At the end of their last session, subjects completed a questionnaire that asked for their preferences as to data and background colors.

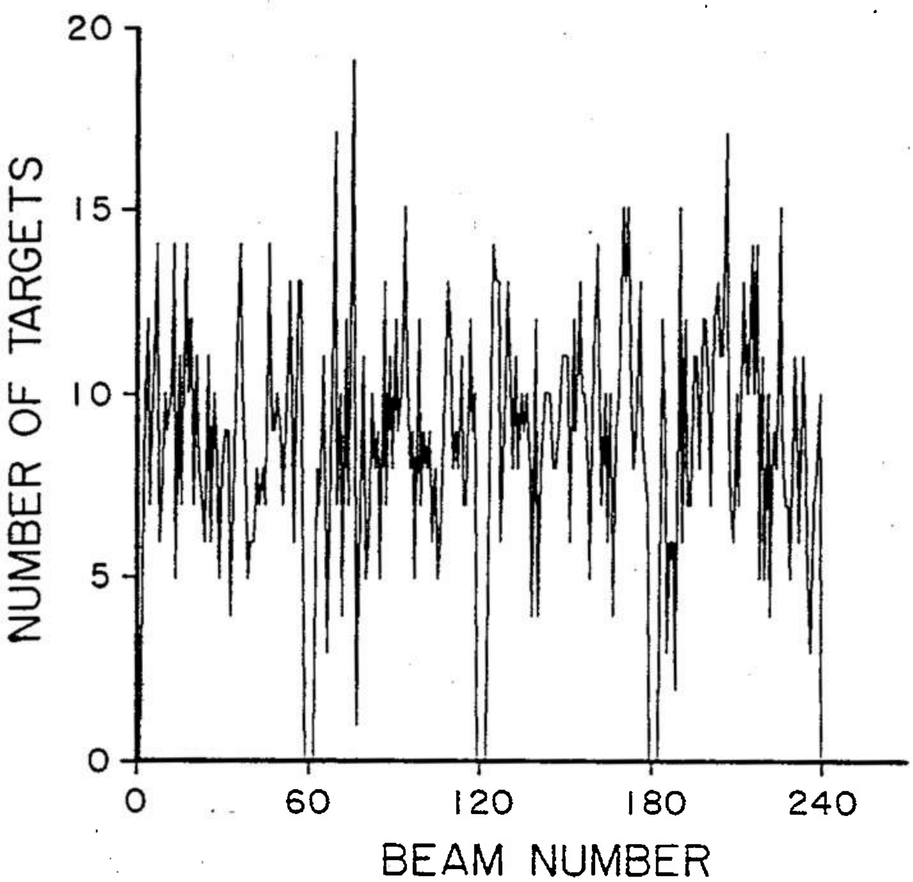


Figure 2. Target Distribution at Each Beam Number

RESULTS

The results are presented in terms of detection times. To translate detection time to SNR, the following expression is used:

$$\text{SNR} = -12\text{ dB} + \text{integer (normalized detection time/10)}.$$

where

$$\underset{\text{time (seconds)}}{\text{Normalized detection}} = \underset{\text{time (seconds)}}{\text{Actual detection}} + 10\text{ sec }(12 + \text{starting SNR}).$$

Figure 3 presents this relationship in graphic form. Only the integer portion is used because of the SNR remaining constant for 10 seconds.

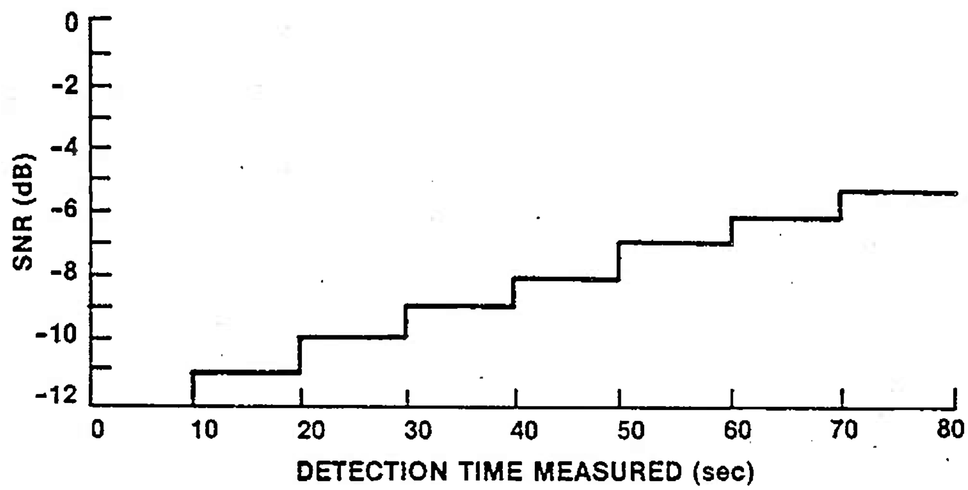


Figure 3. SNR vs Detection Time

The mean detection times of all target types on the blue and black backgrounds for the six subjects are shown in figure 4A. The mean detection times on the blue and black backgrounds were averaged across subjects and foreground color. There was no difference in performance due to background color. Figure 4B shows the average detection times for the three foreground colors (R, red; Y, yellow; and G, green) summed across background color. There was virtually no effect due to foreground color averaged across background color. The differences in mean detection times for each of the foreground colors also did not appear to be significantly different on either background (figure 4C). A two-way repeated-measures analysis of variance (data color x background color x subject) confirmed these results, yielding no statistically significant main effects or interaction.

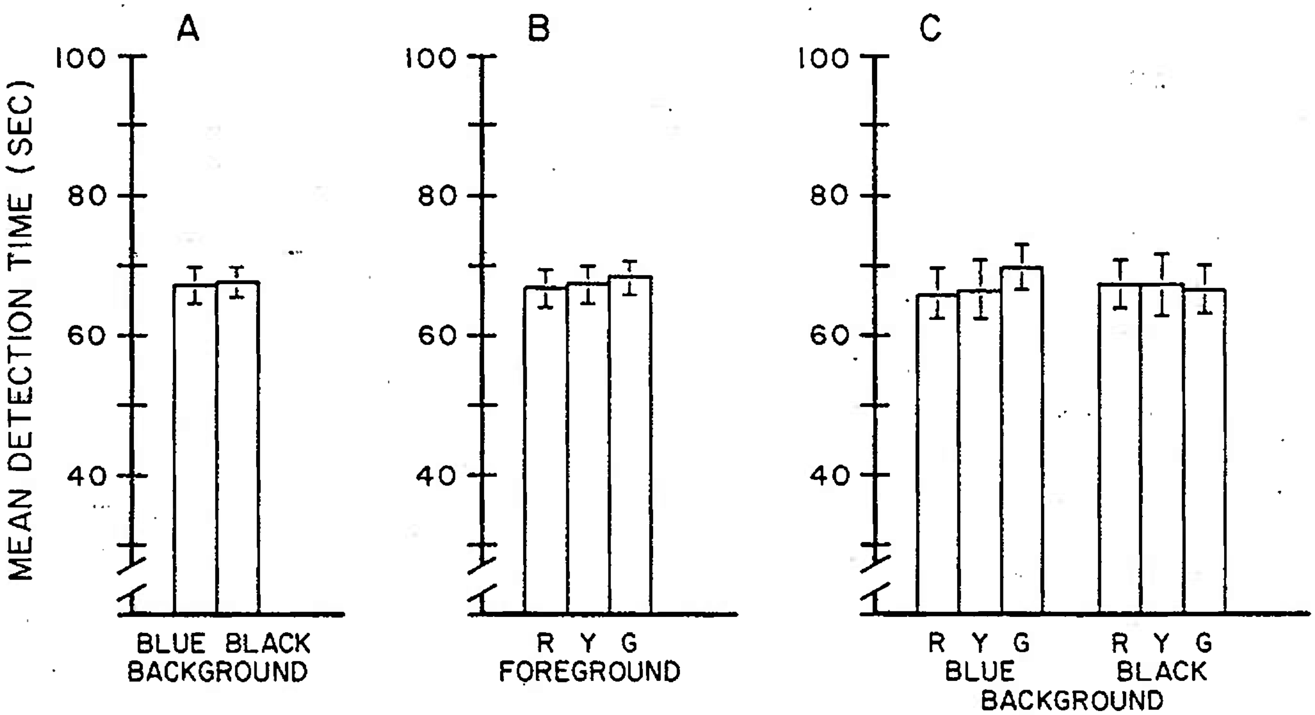
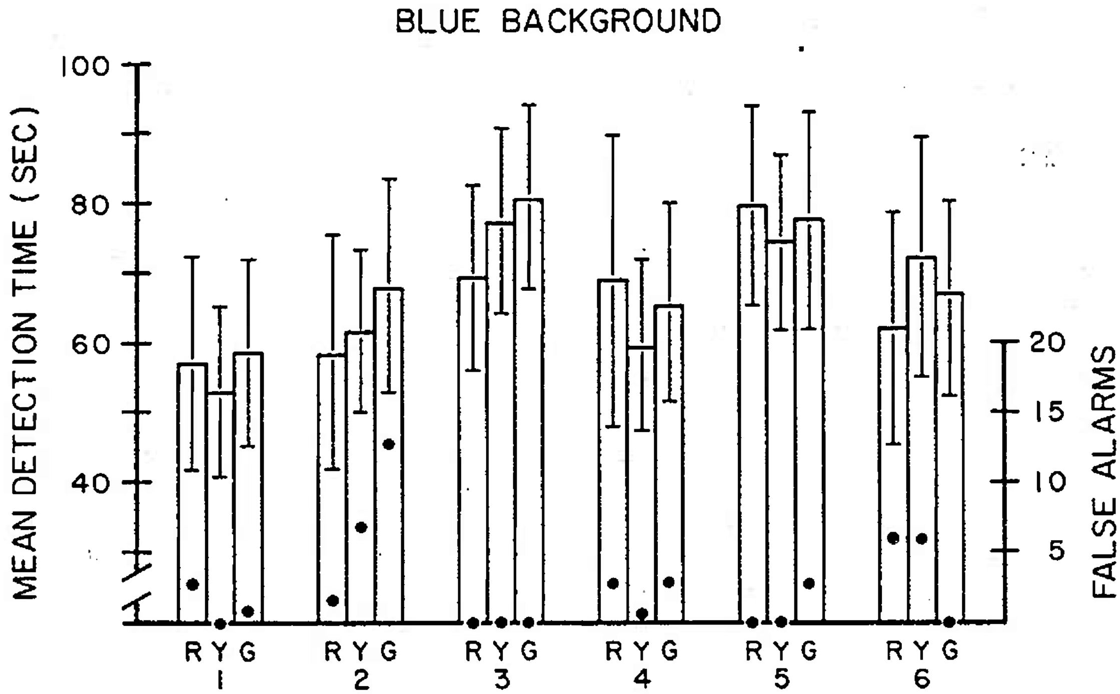


Figure 4. Detection Time vs. Background and Foreground Colors
(Error bars = ±1 standard error of the mean.)

Despite the lack of statistical significance, individual data were examined to reveal any response patterns. Figure 5 shows the average detection times for each subject with the three foreground colors on each background. Two findings are most evident. First, there is a great amount of variability both within and between subjects, as evidenced by the large error bars and a range of average detection times of almost 30 seconds (50 - 80). Second, the average amount of time for a particular subject to detect a target is fairly consistent across backgrounds. Although all subjects were experienced sonar operators, there were consistent differences between them in how fast they detected targets in this task.

The number of times a subject reported detecting a target when none was present ("false alarms") is shown by the filled circles in figure 5. The mean number of false alarms was 3.5 on the black background and 3.0 on the blue background -- not a significant difference. The differences in false alarms for the foreground colors averaged across backgrounds ranged from 2.5 to 3.5, again, not significant.



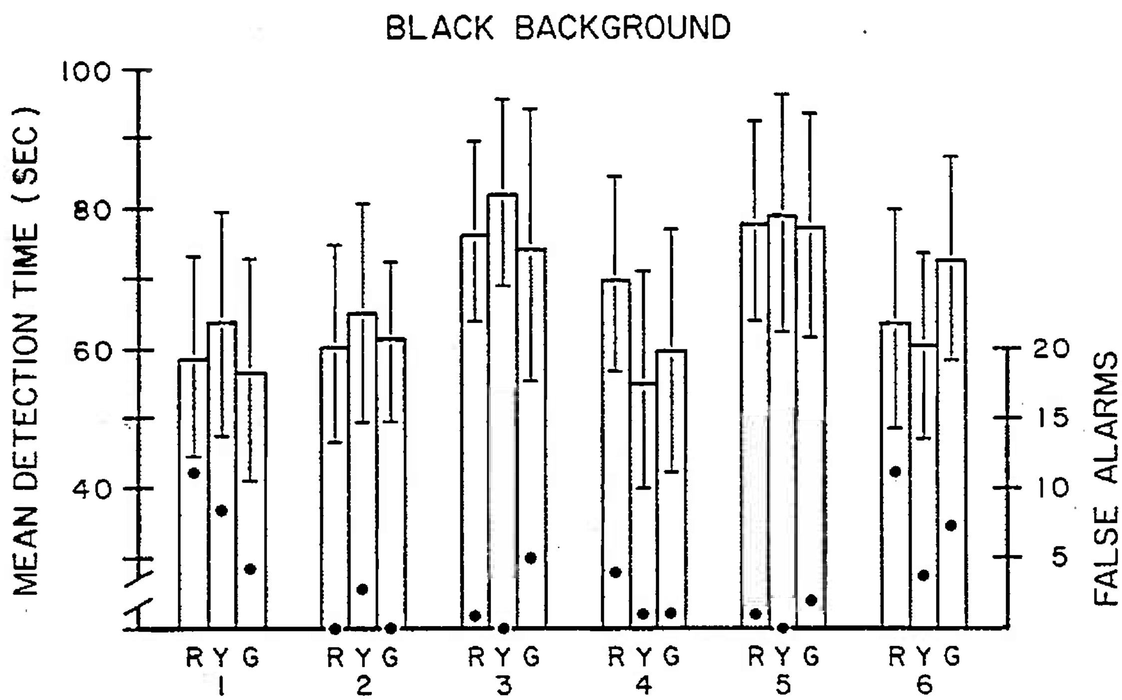


Figure 5. Detection Time vs. Subjects
(Error bar = ±1 standard error of the mean; • = false alarms)

There were some intersubject differences in response styles. Subjects 3, 4, and 5 were consistently low in false alarm rate, averaging only 1.4 per 50 correct detections. Subjects 1, 2, and 6 were generally higher, averaging 4.8 per 50 correct detections. One might expect a pairing of low false alarm rates with longer detection times and vice versa, if the slower subjects adopted a higher criterion for detection, and the faster subjects, a lower criterion. However, the correlation between detection time and false alarms, although in this direction, is not statistically significant. Therefore, the pattern of differences in detection times between subjects does not appear to be based solely on differences in criteria.

There was no agreement among the subjects as to the best color combinations. Four of the six subjects preferred the display that had no background color. The small number of subjects precluded a meaningful statistical analysis.

SUMMARY

These results show that when green, yellow, and red target colors are equated for contrast on blue and black backgrounds, there are virtually no differences in detection performance. Neither the foreground color nor the background color has a significant effect.

This is in agreement with a previous study which showed that an apparent detection advantage for colored targets on a blue background was eliminated when luminance contrasts between target and background were equated.[2] Once again there was no support in the present study for the reports that a blue background was more effective than the standard black CRT background, Nor was there a preference among the six subjects for the blue background, in fact, and there was also a divergence of opinion as to the best foreground color.

The experiment showed that changing the CRT background color to blue would produce no performance benefits. This does not, however, preclude the possibility that a different background color might enhance detection performance.

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1. David F. Neri and David Zannelli, Guidelines for the Use of Color in SUBACS A Displays, Joint NSMRL and NUSC Report No. 1032, October 1984.

2. David F. Neri, S. M. Luria, and David A. Kobus, Visibility of Various Target-Background Color Combinations Under Different Chromatic Ambient Illuminations, NSMRL Report No. 1027, August 1984.

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